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NASA Technical Memorandum 106232

Specification and Testing for Power by Wire Aircraft

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Prepared for the
28th Intersociety Energy Conversion Engineering Conference
sponsored by the American Chemical Society
Atlanta, Georgia, August 8–13, 1993

SPECIFICATION AND TESTING FOR POWER BY WIRE AIRCRAFT

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ABSTRACT

A power by wire aircraft is one in which all active functions other than propulsion are implemented electrically. Other nomenclature are "All Electric Airplane," or "More Electric Airplane." What is involved is the task of developing and certifying electrical equipment to replace existing hydraulics and pneumatics.

When such functions, however, are primary flight controls which are implemented electrically, new requirements are imposed that were not anticipated by existing power system designs. Standards of particular impact are the requirements of ultra-high reliability, high peak transient bi-directional power flow, and immunity to electromagnetic interference and lightning. Not only must the electromagnetic immunity of the total system be verifiable, but box level tests and meaningful system models must be established to allow system evaluation. This paper will discuss some of the problems, the system modifications involved, and early results in establishing wiring harness and interface susceptibility requirements.

INTRODUCTION

Although power by wire has been technically possible for many years, and all major system components have flown, it is only recently that performance requirements and economic reality have combined to push its final development.

In a power by wire aircraft, the electrical power distribution system becomes a flight critical element with stringent reliability requirements. The stated failure rate is less that 10^{-9} failures per hour for flight critical loads. Considering that a "single string" power system will have a typical failure rate of 10^{-6}, much attention must be given to maintaining adequate available power. In order to meet the increased system reliability, redundancy must be invoked and it's status adequately monitored. The sheer complexity of a redundant system is dramatic. As an example, the power distribution system for a Boeing 747 has 200,000 wires, totalling 139 miles, 400,000 connections, 14,000 connectors, and 3000 splices [1]. In practice, a large percentage of failures occur among these connections and interfaces which are not monitored.

As a result over half the "boxes" replaced at the line level checkout as "good" at the repair depot [2].

POWER/CONTROL DISTRIBUTION

The physical complexity of a centralized redundant power system may be greatly reduced by distributing the control across the system. In effect control lines and their complexities are traded for power lines. This is basically a weight trade.

The resulting control complexity may itself be addressed by distributing the control and intelligence itself into the system. This logical evolution is possible by the use of "smart circuitry" such as remote power controllers with built in test and local control intelligence.

A distributed power system with smart distributed control/monitor functions and electric actuators all forming a flight critical system represents new challenges for both design and verification. Low power logic level circuitry will of necessity be placed in remote, more exposed locations. The dynamic characteristics of high power electric actuators will have far reaching effects upon the power system. Unfortunately, many characteristics of the power system are neither defined, nor specified. Among the undefined parameters are such important systematics as common mode rejection, cable inductance, or complex impedances. Fig. 1. (3).

ELECTROMECHANICAL ACTUATORS

In order to reduce weight, electric actuators generally utilize high speed motors and associated reduction gears. Under dynamic conditions the motor may have to accelerate to full speed and then decelerate to a new position in a fraction of a second. Under these conditions considerable energy is drawn to accelerate the rotor then abruptly returns into the power system upon deceleration. This transient energy exchange causes rapidly changing (high di/dt) currents of both polarities to flow in the associated power system. This is a particularly difficult problem in dc systems which typically have diodes in their sources. If power quality is to be maintained, new system designs and verifications must be developed.

Another characteristic of electromagnetic actuators is their potential of creation common mode currents into structures. This results from the application of high de/dt waveforms into both the grounded stator structure and the heat sinks of the associated power electronics. This will necessitate the development of both a common mode current

limit and common mode rejection requirements for all avionics. (Fig. 2.).

LIGHTNING/HIRF

Lightning and high intensity radio frequency (HIRF) threat levels are specified in detail on a system basis.

What must yet be done is to establish these as box level requirements which include the undefined requirements and their effects. Particularly notable by it's omission are any references to grounding or common mode effects, which form such an important part of lightning/EMI tolerance (Figs., 3, 4). Finally verification tests must be established which represent all operating conditions including system reconfiguration to isolate failures.

DEFINING CABLE CHARACTERISTICS

Some preliminary cable measurements have been made in a shielded RF test facility at NASA Lewis. Several configurations of cables were exposed to a 10 v/m field at frequencies from 1 kHz to 1 GHz. The results show that at lower frequencies, the cable configuration will directly impact the system rejection.

In Figure 5, standard #8 aircraft cables with the conductors twisted are compared to cables placed parallel at a 2 cm separation as specified in MIL 462. It can be seen that twisting the cables rejects frequencies up to about 200 kHz. This is a direct consequence of the lower inductance of the twisted pair cable.

In Figure 6, the 20 kHz three conductor flat cable developed for SSF is tested. This cable has very low inductance being essentially a double sided stripline. The flat cable alone rejects frequencies up to about 1 MHz. Also tested was the 20 kHz cable connected to a transformer with the output of the transformer being measured. With the transformer, this configuration only rejects frequencies up to 200 kHz. This is probably due both to the reduced effectivity of the electrostatic shields at the high frequencies, and the effects of system unbalance causing normal mode to common mode conversion. The effects are additive and typically exhibit the classical 20Db/decade variation. This raises the question of possible requirements for source and line balance. The apparent offset of the transformer connection at lower frequencies is due to the turns ratio.

CONCLUSIONS

In order to design and verify the electric power system for more electric and Power By Wire aircraft, existing standards and procedures must be fully reviewed, overhauled, and augmented. The immensity of this tast must not be underestimated. Taking only the SAE Aerospace Council as an example, the electric airplane requirements will span and alter the interfaces between at least thirteen committees, [Fig. 7]. Concurrent design practices must be instituted during the development phase to redefine the interfaces so that the committees will be able to adjust their specifications as required. To proceed without performing this step will risk eventual disaster at a point in the design cycle where recovery is most painful.

REFERENCES

(1). "400,000 Connections," Engineering, September 1989.

(2). "How Failure Prediction Methodology Affects Electronic Equipment Design," Leonard, Charles T., Boeing Commercial Airplanes.

(3). "Power System Characteristics for more Electric Aircraft," Hansen, Irving G., SAE Technical Paper 931406.

(4). "Lightning Protection of Aircraft," Fisher, F. A. and Plumer, J. A., NASA Reference Publication 1008, October 1977.

(5). "Lightning Test Waveforms and Techniques for Aerospace Vehicles and Hardware," SAE AE4L Committee Report, June 20, 1978 (Blue Book).

(6). "Test Waveforms and Techniques for Assessing the Effects of Lightning Induced Transients," SAE AE4L Committee Report, December 15, 1981 (Yellow Book).

(7). "Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning," SAE AE4L Committee Report, Revision B, January 1989 (Orange Book) (Proposed FAA Advisory Circular).

(8). "Certification of Aircraft Electrical/Electronic Systems for Operation in the High Intensity Radiated Fields (HIRF) Environment," SAE AE4 Committee Report, September 15, 1992 (Proposed FAA Advisory Circular).

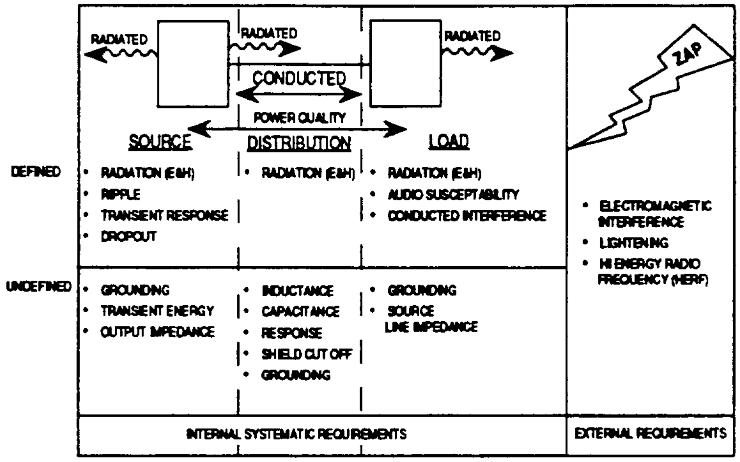


Figure 1. Power System Interfaces.

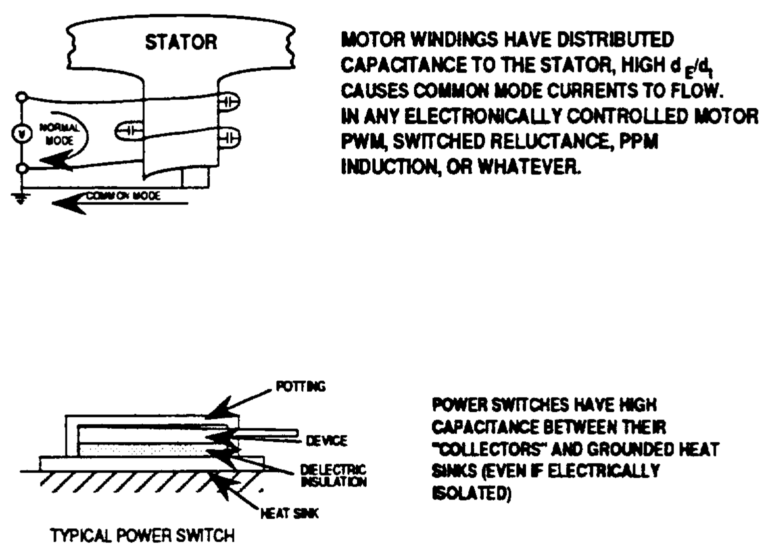
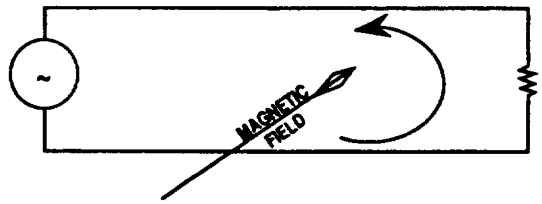


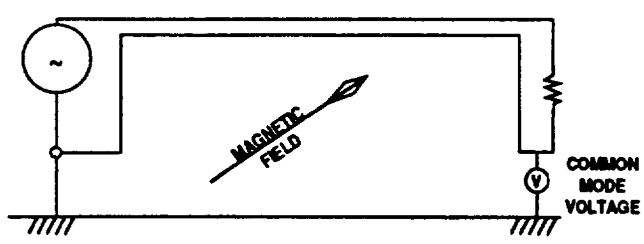
Figure 2. Common Mode Coupling (de/dt).



- PROBLEM - EXTERNAL MAGNETIC FIELD INDUCES A NORMAL MODE CURRENT INTO DISTRIBUTION LOOP. ADDS OR SUBTRACTS FROM DISTRIBUTION.

- CURE - MINIMIZE HARNESS SELF INDUCTANCE TWIST WIRES OR USE LOW INDUCTANCE FLAT CABLE.

Figure 3. Lighting/EMP Tolerance (Normal Mode).



- PROBLEM - MAGNETIC FIELD OR LIGHTNING CURRENTS IN STRUCTURE CAUSE COMMON MODE VOLTAGES TO APPEAR.

Figure 4. Lighting/EMP Tolerance (Common Mode).

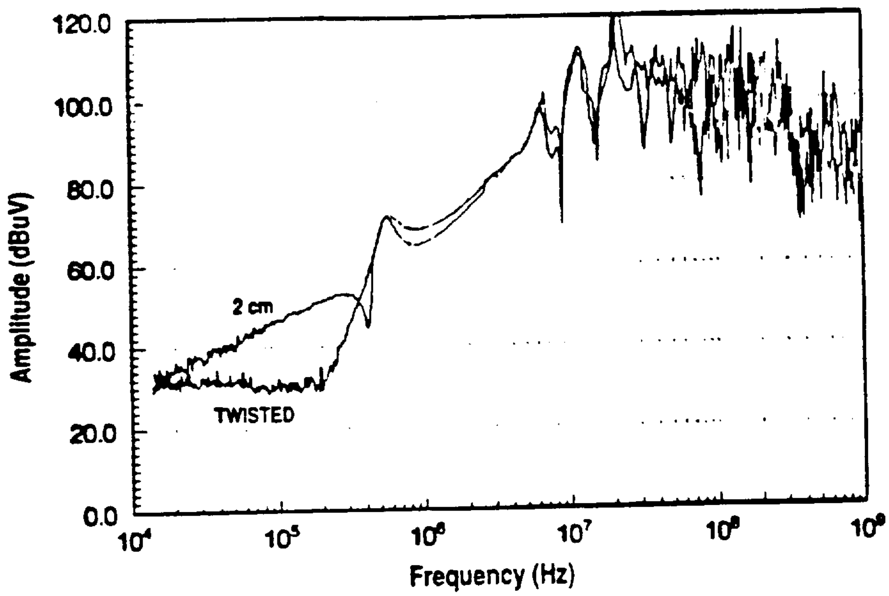


Figure 5. Effects of Twisting Standard Cable.

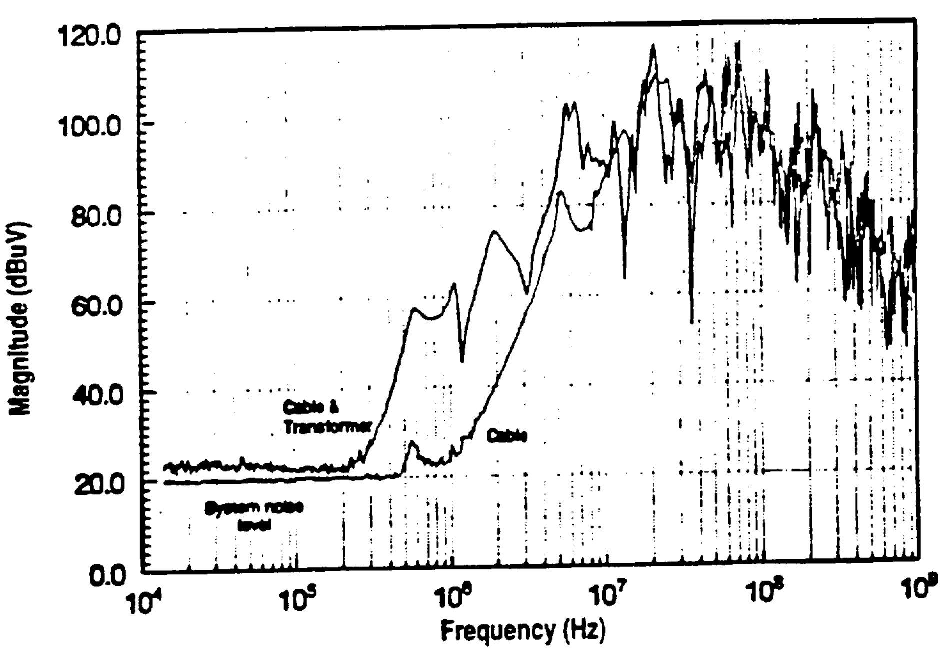


Figure 6. Effect of Double Shielded Transformer upon Low Inductance Flat Cable.

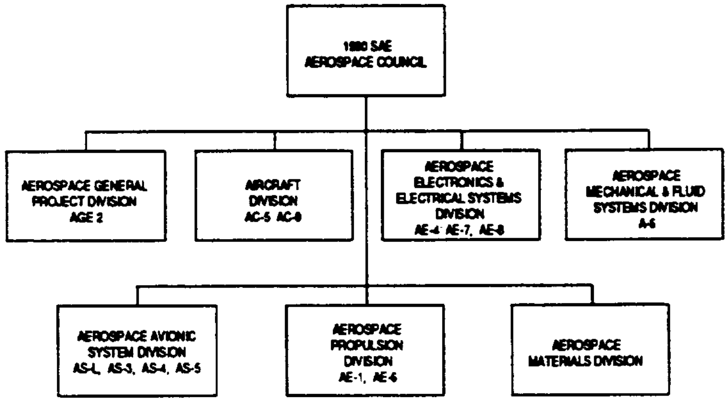


Figure 7. Committees Directly Impacted by New Interface Requirements for Power by Wire Aircraft.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 1993	Technical Memorandum

4. TITLE AND SUBTITLE

Specification and Testing for Power by Wire Aircraft

5. FUNDING NUMBERS

WU–538–01–11

6. AUTHOR(S)

Irving G. Hansen and Barbara H. Kenney

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
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Cleveland, Ohio 44135–3191

8. PERFORMING ORGANIZATION REPORT NUMBER

E–7951

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, D.C. 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TM–106232

11. SUPPLEMENTARY NOTES

Prepared for the 28th Intersociety Energy Conversion Engineering Conference sponsored by the American Chemical Society, Atlanta, Georgia, August 8–13, 1993. Responsible person, Irving G. Hansen, (216) 433–5316.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category 20

12b. DISTRIBUTION CODE

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14. SUBJECT TERMS

Electric airplane; Aircraft electric power

15. NUMBER OF PAGES

8

16. PRICE CODE

A02

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	